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Latest results from irradiated Digital Pixel Test Structures produced in 65 nm TPSCo CMOS process

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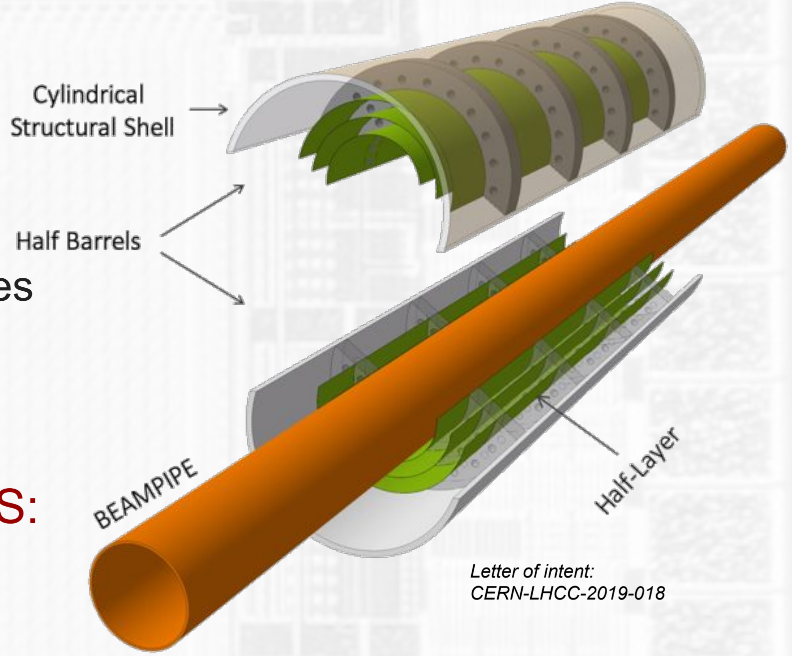
3. High-D Consortium Meeting
09 - 10 February 2023

10 February 2023

From ALPIDE to a 65 nm CMOS MAPS prototype: ALICE inner tracker upgrades

- Further improvement on material budget possible (wrt. ITS2 with ALPIDE sensors)
  - Improve pointing resolution by factor 2
  - Improve tracking of low momentum particles
- Get closer to the interaction point



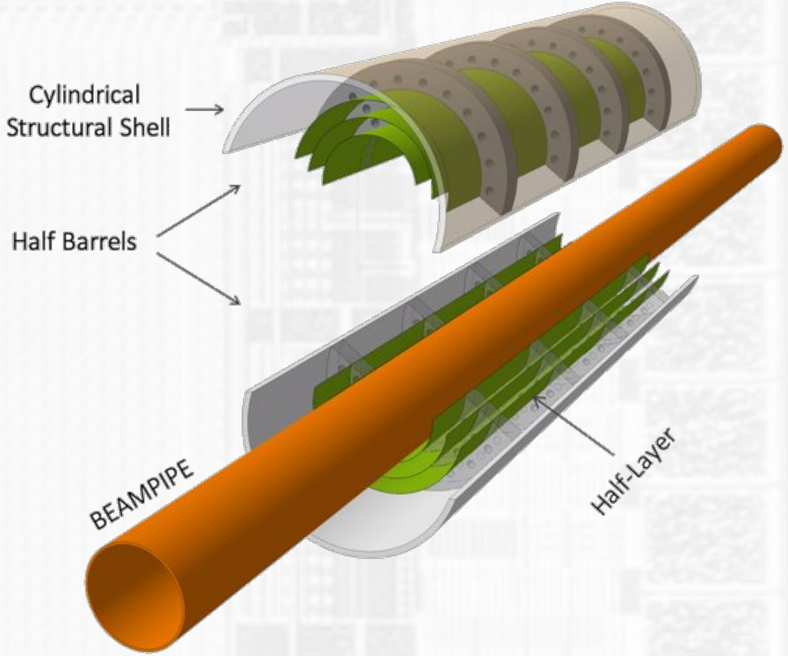
Letter of intent: CERN-LHCC-2019-018

- Move to truly-cylindrical, wafer-scale MAPS: **ITS3**
- Sensors self-supported due to bending
- Thin sensors O(30 µm)
- Cooled by air flow
- Optimised power consumption

- New generation of tracking detectors
- R&D started on new sensors to face the challenges

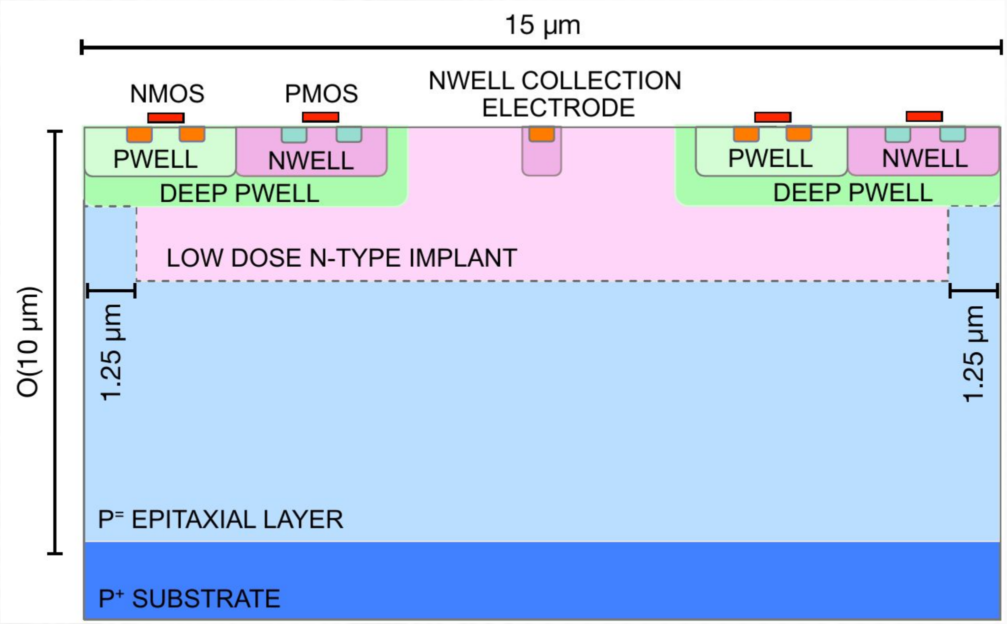
From ALPIDE to a 65 nm CMOS MAPS prototype: A new sensor for the ITS3

- 65 nm CMOS technology node is key
  - Larger available wafers (30 cm)
  - Stitching available for production of large area sensors
- Smaller feature size
  - Realise smaller pixels with in-pixel signal processing
  - Manageable occupancy at high track densities



- Small scale prototypes are available since 2021
- Multi Layer Reticle 1 (MLR1) submission
  - Joint effort of CERN EP R&D and ALICE ITS3

The MLR1 Digital Pixel Test Structure (DPTS)

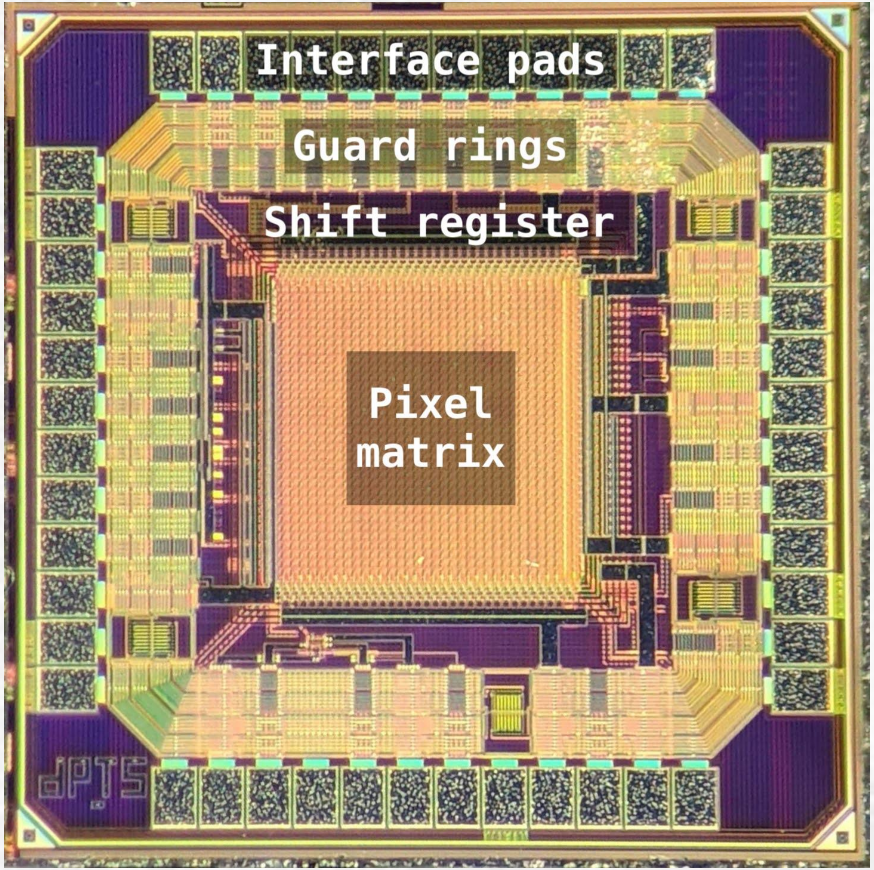


- Active epitaxial layer of ~8 µm
- Deep n-implant to fully deplete epitaxial layer

- Gaps for having a lateral field component
- Enhance charge collection in a single pixel
- Higher operating margin due to larger seed pixel signal

- Produced in “modified process”
- Pixel cross section not to scale

The MLR1 Digital Pixel Test Structure (DPTS)

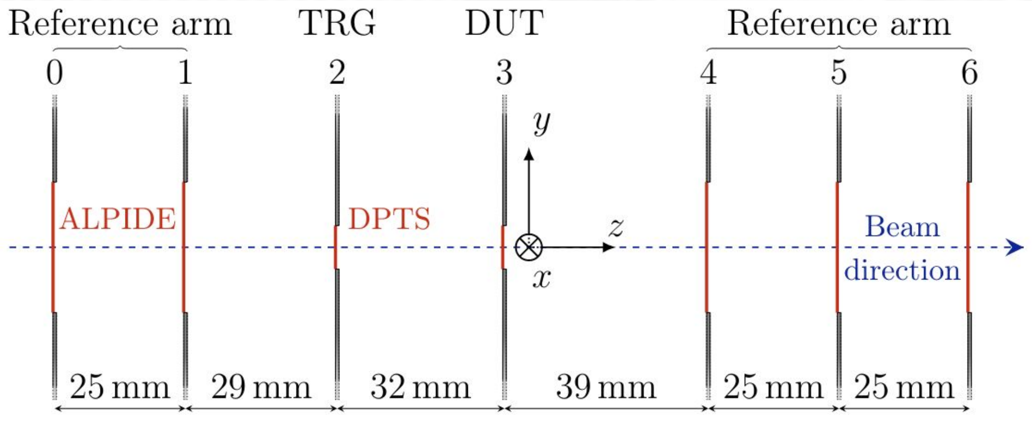


- Full pixel matrix with in-pixel signal discrimination
  - Test front-end and digital building blocks
  - In-beam sensor performance characterisation
- 480 µm x 480 µm active area
- 32 x 32 pixel (15 µm x 15 µm)

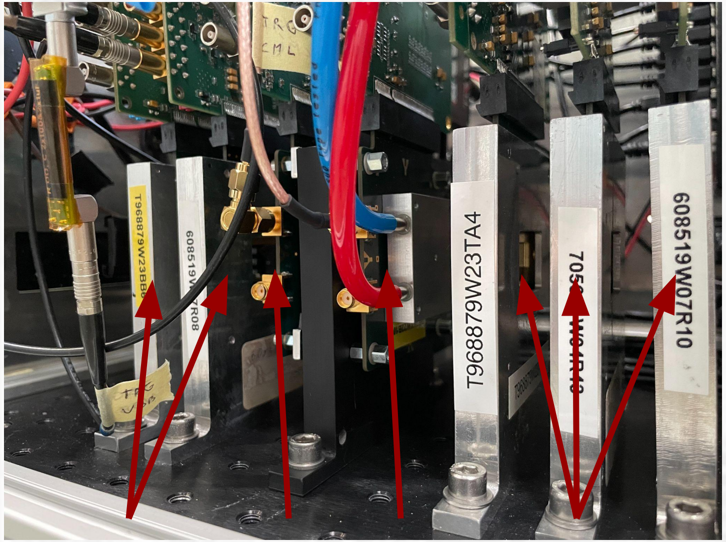
- Asynchronous digital readout (single output line)
- Time-encoded position information
- Access to signal time over threshold

Multiple testbeam campaigns

- DESY
- CERN SPS
- CERN PS
  - 10 GeV/*c* positive hadrons

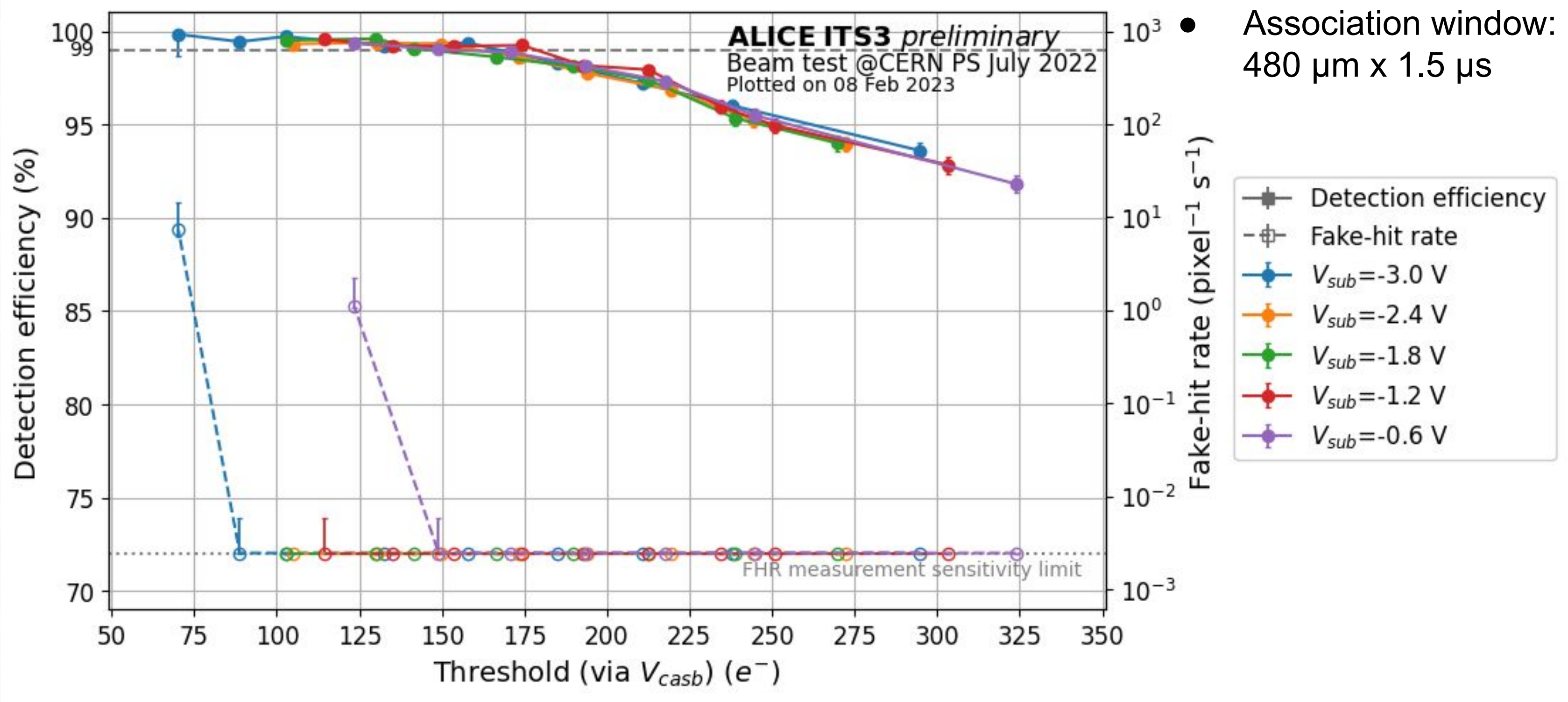


- Temperature kept at 20°C with chiller
- In-situ fake hit rate, threshold measurements
- In-situ position decoding calibration
- DPTS waveforms read out with oscilloscope
- Data analysis with Corryvreckan
  - Alignment, Tracking, DUT association
  - **https://gitlab.cern.ch/corryvreckan/corryvreckan**



ALPIDEs TRG DUT ALPIDEs

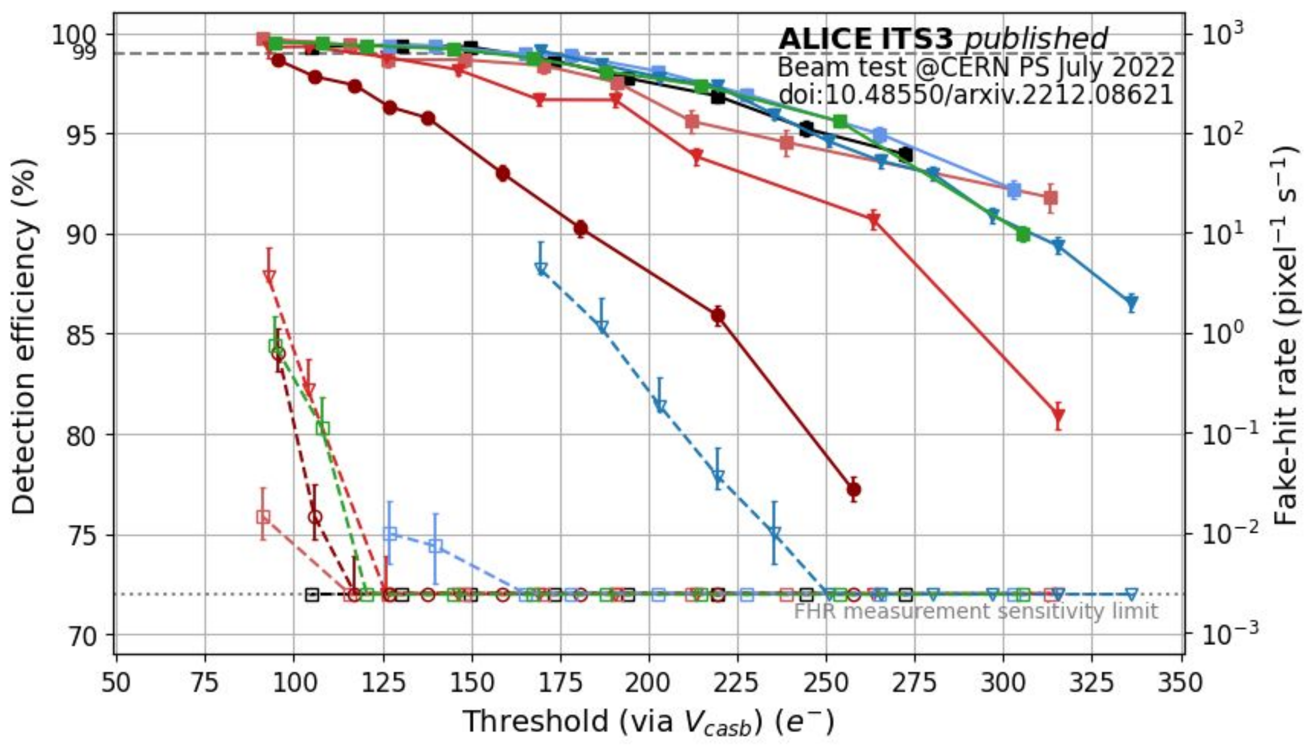
DPTS performance - Detection efficiency
Non-irradiated



- Association window: 480 μm x 1.5 μs

- Detection efficiency exceeds 99% for a wide range of working points
- Overall low noise level

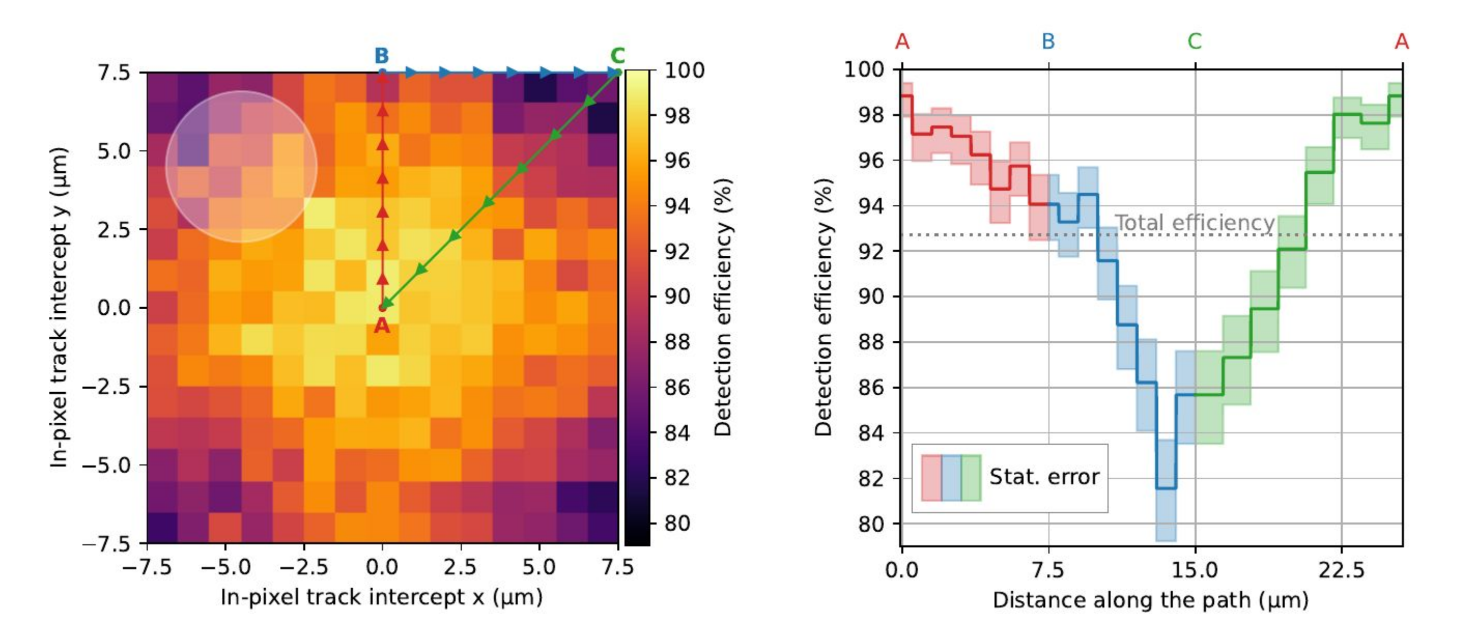
DPTS performance - Detection efficiency TID and/or NIEL irradiated



- Association window: 480 µm x 1.5 µs

- DPTS stays efficient across different irradiation levels
- Overall noise level is increased (especially for TID)

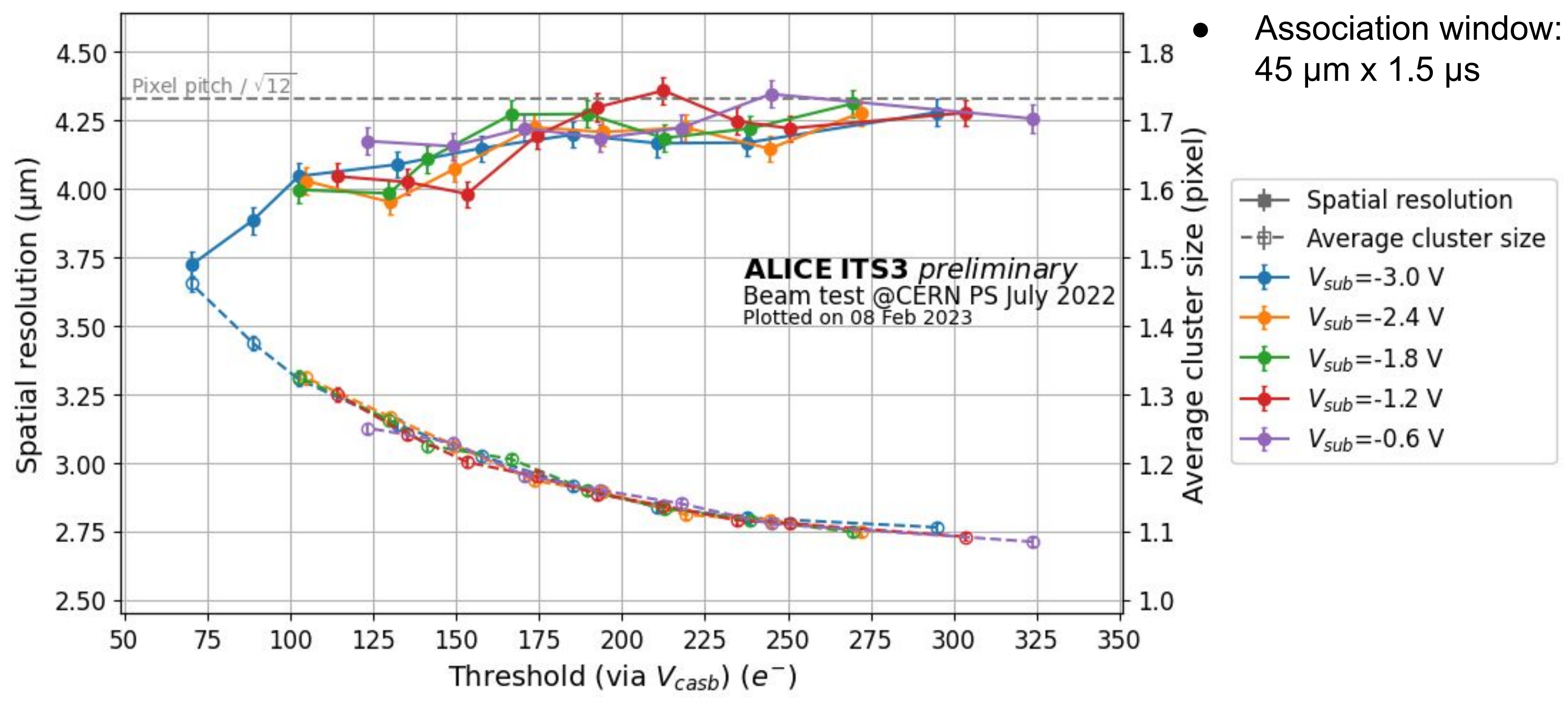
DPTS performance - Origin of detection efficiency loss



- Highest NIEL dose: $10^{15}\,1\mathrm{MeV}\,\mathrm{n_{eq}}\,\mathrm{cm}^{-2}$
- Intermediate threshold: 155 electrons
- 2.4 µm track intercept uncertainty

- Lower detection efficiency with increasing distance to the collection diode
- Similar observation for non-irradiated sensor at **higher** threshold values

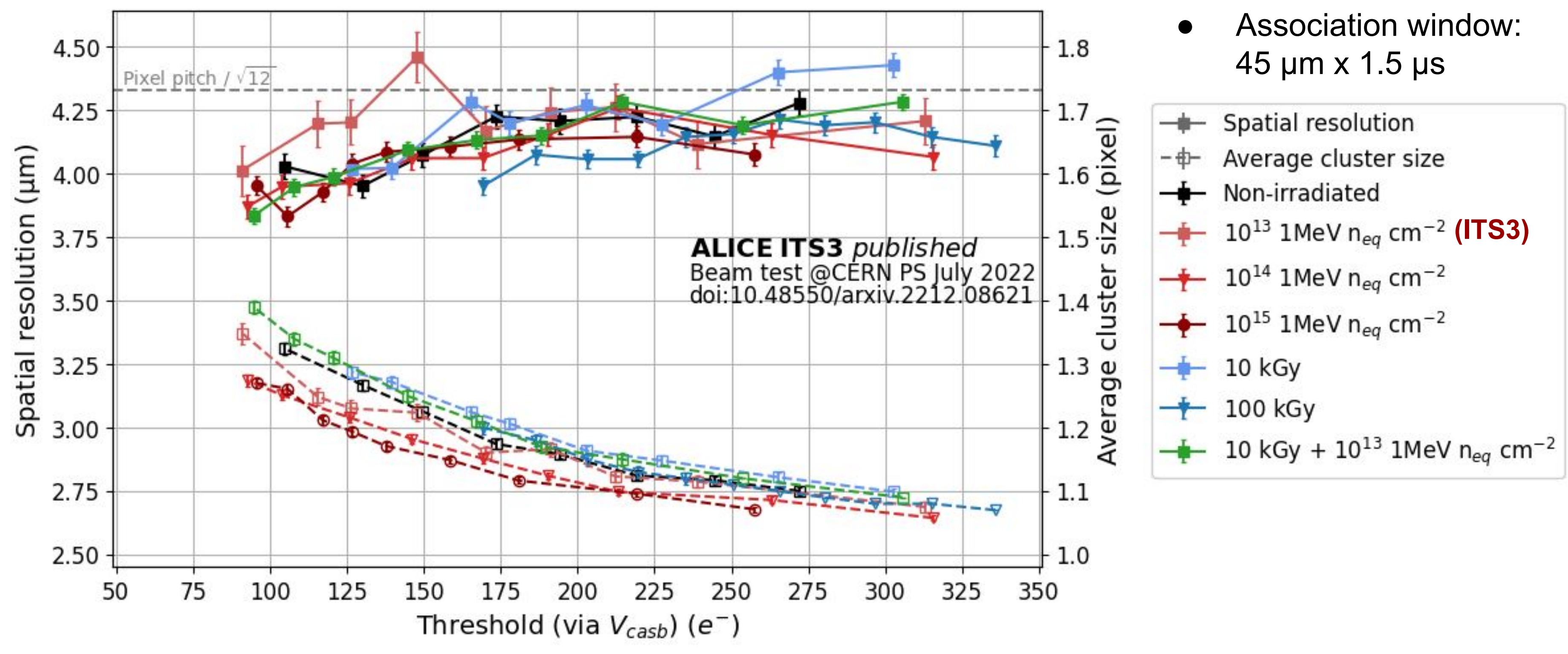
DPTS performance - Spatial resolution Non-irradiated



- Association window: 45 µm x 1.5 µs

- Dominated by small pixel size
- Spatial resolution improves with increasing cluster size

DPTS performance - Spatial resolution TID and/or NIEL irradiated

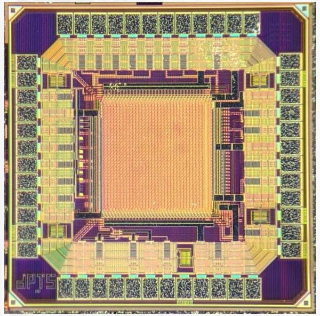


- Association window: 45 µm x 1.5 µs

- No strong dependence on irradiation level
- Visible cluster size ordering according to NIEL dose

Summary and Outlook

- 65 nm CMOS technology qualified for MAPS used in particle/nuclear physics
- In-beam characterisation of irradiated DPTS sensors



- Operational range for high irradiation levels up to: 100 kGy and $10^{15}\,1\mathrm{MeV}\,\mathrm{n_{eq}}\,\mathrm{cm}^{-2}$
  - At room temperature!
  - Still reaches 99% detection efficiency
- Spatial resolution matches expectation

- DPTS characterisation paper **https://arxiv.org/abs/2212.08621**
- Additionally covers:
  - Full electrical characterisation
  - ^{55}Fe response
  - Timing resolution
- New testbeam measurements:
  - Inclined sensors
  - extended operating ranges (0 V up to -4.8 V back-bias)
  - More irradiated sensors (up to 500 kGy)
- Bending of DPTS sensors in progress

Excellent results from MLR1 submission

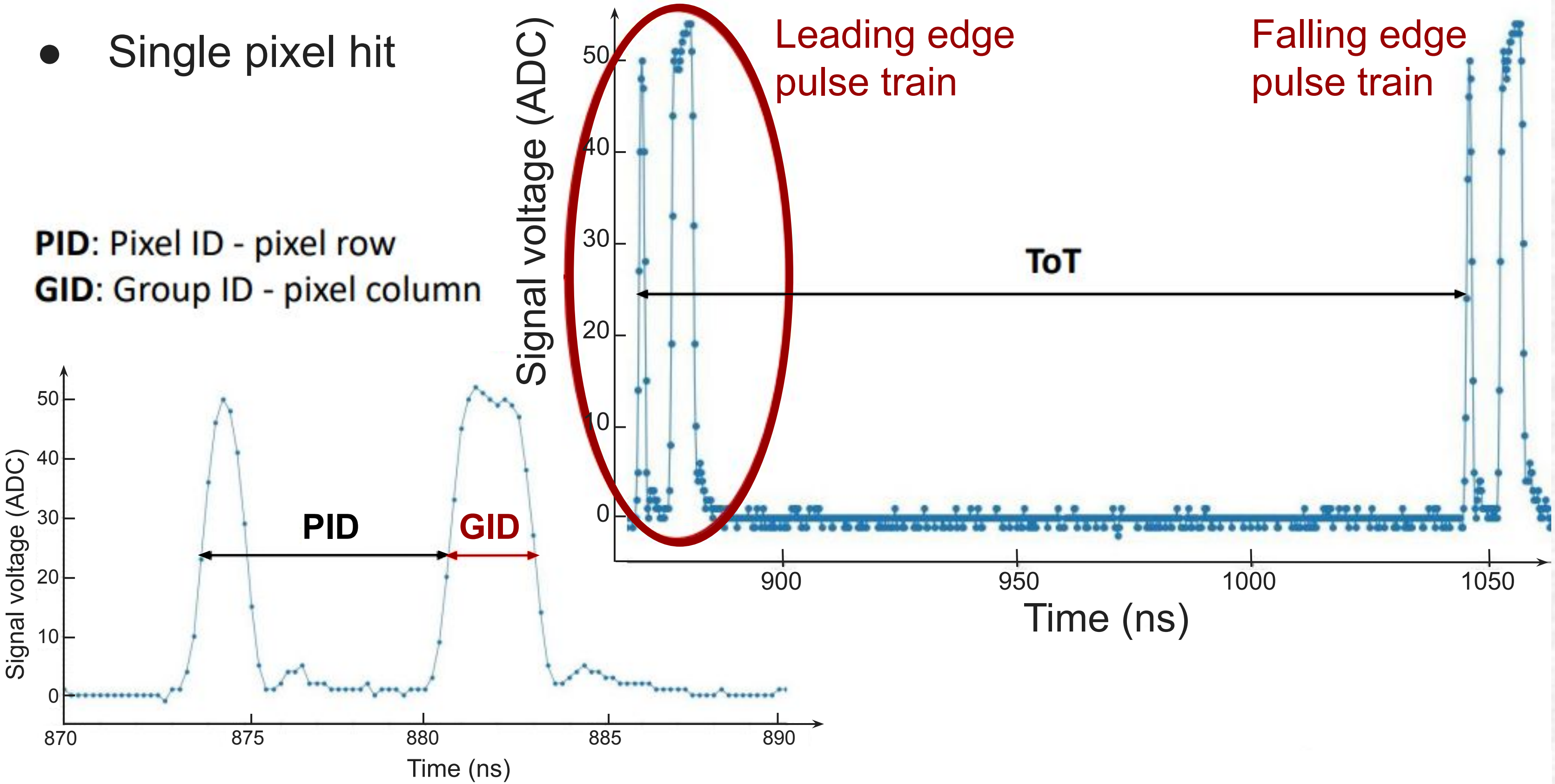
- Engineering run upcoming with stitched sensors

Backup

DPTS signals and position decoding

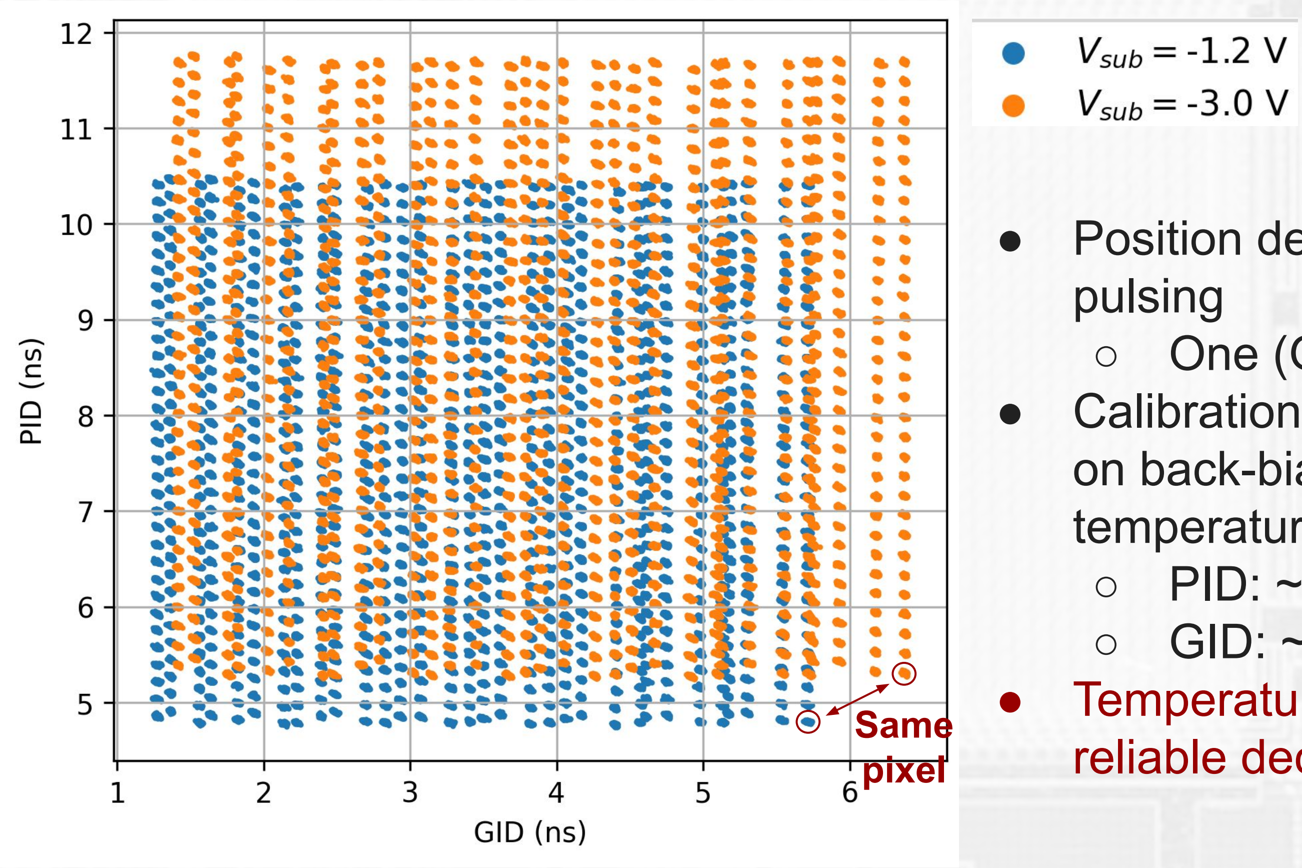
- Single pixel hit

PID: Pixel ID - pixel row
GID: Group ID - pixel column



- Multiple pixel hits may cause signal collisions

DPTS signals and position decoding



- Position decoding calibration via pulsing
  - One (GID,PID)-point per pixel
- Calibration map strongly depends on back-bias voltage and temperature
  - PID: ~0.04 ns / 5°C
  - GID: ~0.02 ns / 5°C
- Temperature control needed for reliable decoding